Accumulation rates of carbon, nitrogen and phosphorus in petrel colony soil: Adams Island, New Zealand subantarctic

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Abstract

Previous research establishing low levels of nutrient retention in petrel colony soils was based on a single soil profile with a single radiocarbon date. Because of the ecological implications of the wide dispersion of nutrients implied by low nutrient retention, replication of the original study is necessary. Four profiles (0-75 cm) 50 m apart were excavated in a mixed species petrel colony on Adams Island (Auckland Islands group) and inventories of C, N, and P determined. Radiocarbon analyses were carried out at three depths in one of the profiles, to see if accumulation rates were consistent. Accumulation rates based on the 2σ calibrated radiocarbon age over the 0-67.5 cm depth interval (0.123-0.134 kg C m^{-2} yr^{-1}, 3.99-4.35×10^{-3} kg N m^{-2} yr^{-1}, 9.05-9.87×10^{-5} kg P m^{-2} yr^{-1}) agreed with rates calculated over the 0-52.5 cm depth interval (0.114-0.272 kg C m^{-2} yr^{-1}, 3.99-9.52×10^{-3} kg N m^{-2} yr^{-1}, 9.53-22.7×10^{-5} kg P m^{-2} yr^{-1}); elemental inventories were consistent across all profiles. The radiocarbon date at the third depth interval (0-37.5 cm) gave a calendar age range that was too broad for meaningful accumulation rates to be calculated. While accumulation rates were approximately double the previously reported rates obtained from Taukihepa/Big South Cape (Rakiura/Stewart Island), the proportions of gross N and P input retained by colony soil were still extremely low. The higher accumulation rates reported in the present study can be explained by the colder climate and lower leaf litter quality associated with forest on Adams Island.

Keywords: Auckland Islands - elemental accumulation - peat - radiocarbon.

Introduction

Breeding petrels (non-albatross Peocellariiformes) are of major ecological significance to terrestrial ecosystems because of the large amounts of essential nutrients they deposit in their breeding environment (Furness 1991; Anderson & Polis 2004) and the extent to which they engineer the soil properties of their breeding colonies (Bancroft *et al.* 2004). Although petrel nutrients are incorporated in forest plants and animals occupying breeding colonies (Hawke & Holdaway 2005, 2009), soil chemistry studies suggest that petrel colony soils retain the added nutrients only poorly (Hawke & Newman 2004; Hawke 2005). Low levels of nutrient retention imply dispersion to the wider environment, affecting (for example) nutrient dynamics in waterways (Harding *et al.* 2004).

Replication is a key component of ecological studies. The results obtained by Hawke & Newman (2004) showing low levels of nutrient retention came from one soil profile with a single radiocarbon date, while the calculations of Hawke (2005) were indirect, being based on literature values of guano deposition by petrels. Such minimalism is in some respects entirely justified; soil profile excavation can be somewhat destructive in the context of a petrel colony, and radiocarbon analysis is expensive. Nevertheless, the collection of more data to support or refute these studies would be most helpful.

This study reports elemental accumulation rates (carbon, C; nitrogen, N; phosphorus, P) and supporting elemental inventories from a mixed-species petrel colony on Adams Island. The results are compared with those reported by Hawke & Newman (2004) for Taukihepa/Big South Cape, an island off the western coast of Rakiura/Stewart Island. The effect of accumulation depth interval and radiocarbon sample pre-treatment on calculated elemental accumulation rates were also explored.

Materials and methods

Adams Island (10,119 ha) is the second-largest island of the Auckland Islands group (50°26'-50°56'S, 165°52'-166°22'E) and faces north to the main Auckland Island (46,000 ha) across Carnley Harbour. Peat soil covers most of the island (Leamy & Blakemore 1960). Vegetation is a mosaic of southern rata (*Metrosideros umbellata*) forest around the coast which grades quickly into a shrubland mosaic and then tussock grassland with increasing altitude (Leamy & Blakemore 1960, Godley 1965). Six species of petrel (white-headed petrel *Pterodroma lessonii,* grey-backed storm petrel *Oceanites nereis*, black-bellied storm petrel *Fregetta tropica*, sooty shearwater *Puffinus griseus*, common diving petrel *Pelecanoides urinatrix*, and Antarctic prion *Pachyptila desolata*) breed in a 20-30 m wide band along the forest margin around the Adams Island coast. Burrow density is c. 0.2-0.5 m^{-2} (Hawke & Holdaway 2009). Unlike the main Auckland Island, Adams Island is essentially pristine and has never seen introduced mammals.

Depth profile samples were collected at 0-0.15, 0.15-0.30, 0.30-0.45, 0.45-0.60 and 0.60-0.75 m from four freshly dug soil pits in January-February 2004; an image of the location of the soil sampling is given in Hawke & Holdaway (2009). The soil pits were 50 m apart within 20 m of the sea along a section of coast immediately west of the enclosed bay adjacent to the Department of Conservation (DoC) hut. Vegetation was southern rata – inaka (*Dracophyllum longifolium*) forest. The slope was not measured but was similar at all pit sites. Soil samples were individually packed into double polythene bags, then stored in closed bins away from direct sunlight. Once back in the laboratory, the bins were stored at 4°C. Sub-samples for analysis were removed in April 2004, and dried at 60°C. A sulfidic odour was noted during sub-sampling in the 0-0.15 and 0.45-0.60 m samples from Profile 1. Prior to analysis, leaves and twigs were removed by hand picking.

Soil analytical concentrations were converted to a volume basis using bulk densities measured on c. 500 cm^3 sections of each sample slab. Analysis of dried soil used elemental analysis-isotope ratio mass spectrometry (IRMS) (Europa Geo 20/20; GNS Science, Lower Hutt, New Zealand; C, N) and wavelength-dispersive X-ray fluorescence (XRF) (SpectraChem Analytical Ltd, Lower Hutt; P).

Accelerator mass spectrometry (AMS) analysis for radiocarbon was carried out by Rafter Radiocarbon Laboratory (GNS Science) on representative subsamples from three depth intervals from Profile 2; 30-45, 45-60, and 60-75 cm. In each case, the peat was sequentially wet-sieved through 850, 200, 90, 45, and 6 µm sieves. After drying in a vacuum oven and prior to AMS analysis, the fraction retained on the 6 µm sieve was sequentially leached with 0.5 mol l^{-1} hydrochloric acid, 0.1 mol l^{-1} sodium hydroxide + 0.1 mol l^{-1} sodium pyrophosphate, and 0.5 mol l^{-1} hydrochloric acid. The 60-75 cm sample was analysed both before and after the chemical leaching process. Conversion from conventional radiocarbon age to calendar age used the Southern Hemisphere calibration of McCormac *et al.* (2004). Accumulation rates were calculated from the upper and lower limits of the 2σ calibrated radiocarbon ages, and used the mid-point of the relevant depth interval.

Results

The conventional radiocarbon ages of the leached samples were 176±30 BP (30-45 cm; NZA 26097), 293±35 BP (45-60 cm; NZA 26098), and 533±30 BP (60-75 cm; NZA 25055). The conventional radiocarbon age of the unleached 60-75 cm sample was younger (436±30 BP; NZA 25054), showing that the leaching process successfully removed more recent, mobile C carried down-profile.

The elemental inventories for all profiles and the accumulation rates for Profile 2 are given in Table 1, along with previously published data from Hawke & Newman (2004) for comparison. Accumulation rates were based on the calibrated 2σ radiocarbon ages, being 1508-1796 AD for 45-60cm and 1402-1452 AD for

Table 1. Elemental inventories (kg m^{-2}; 0-75 cm unless stated) and accumulation rates (based on 0-52.5 cm for 0-60 cm inventories or 0-67.5 cm for 0-75 cm inventories; kg m^{-2} yr^{-1}). The accumulation rate ranges are based on the 2σ calibrated data calculated from the conventional radiocarbon ages. Data from Hawke & Newman (2004) based on a 0-70 cm depth interval are shown for comparison.

Profile	Carbon	Nitrogen	Phosphorus
1	77.0; na	2.19; na	0.0549; na
2 (0-60 cm)	56.6; 0.114-0.272	1.98; $3.99\text{-}9.52\times10^{-3}$	0.0473; $9.53\text{-}22.7\times10^{-5}$
2	73.9; 0.123-0.134	2.40; $3.99\text{-}4.35\times10^{-3}$	0.0545; $9.05\text{-}9.87\times10^{-5}$
3	78.8; na	1.82; na	0.0557; na
4	80.1; na	1.83; na	0.0812; na
Taukihepa[A]	42.9; 0.061-0.076	1.39; $2.0\text{-}2.4\times10^{-3}$	0.0252; $3.6\text{-}4.4\times10^{-5}$
Putauhinu[A]	42.9; na	1.95; na	0.0399; na

[A]Hawke & Newman (2004)

60-75 cm. The 2σ radiocarbon calibration confidence interval of the 30-45 cm sample (1666-1950 AD) was too broad to give meaningful accumulation rates. Profile 2 (the profile used for accumulation rate determinations) showed a C inventory (0-75 cm) that was lower than the other three profiles; the N inventory was slightly higher, and the P inventory was within the range of the other profiles. The C, N, and P inventories from the present study were all substantially higher than those from petrel colonies on islands around Rakiura/Stewart Island (Hawke & Newman 2004).

Accumulation rates for all three elements were in agreement across the two depth intervals, although the rates over the 0-67.5 cm interval tended to fall at the lower end of the rates calculated for the 0-52.5 cm interval.

Discussion

The elemental accumulation rates from the present study were approximately double those previously reported for Taukihepa by Hawke & Newman (2004; Table 1), and were consistent across both accumulation depths. On Taukihepa, Hawke & Newman (2004) found that 0.6-2.2% of N and 0.1-0.6% of P were retained over the 567-705 year accumulation period, based on literature estimates of guano deposition. Applying the same literature estimates (0.11-0.31 kg N m^{-2} yr^{-1}, 0.008-0.029 kg P m^{-2} yr^{-1}; Furness 1991) to the 0-67.5 cm accumulation rates from the present study yielded retention rates of 1.3-4.0% of N and 0.3-1.2% of P over the 552-602 calendar year accumulation period. Consequently, the accumulation rates from the present study do not affect the conclusion that nutrients brought ashore by breeding petrels are poorly retained by colony soils.

The higher accumulation rates on Adams Island can be explained by a combination of a colder climate and poorer litter quality (Aerts 1997, Liski *et al.* 2003). At 47°14'S, Taukihepa is 3° latitude north of Adams Island and is surrounded by a mix of subtropical and subantarctic waters; Adams Island is clearly subantarctic. The vegetation from the study area on Adams Island (southern rata – inaka forest) differs from that on Taukihepa, where tupare (*Olearia lyalli*) forest predominates. Southern rata foliage from the vicinity of Profile 2 had a molar C:N ratio of 63.1 (Hawke & Holdaway 2009), while tupare foliage from a seabird breeding island (North East Island, The Snares) had a much lower C:N ratio of 38.8 (Hawke & Newman 2007). Inaka foliage has an even higher C:N ratio of 90.0 (Hawke & Newman 2007), although this value was from a low-nutrient site (Mason Bay, Rakiura/Stewart Island).

The possibility that the difference in elemental accumulation between Adams Island and Taukihepa resulted from the high spatial variability commonly observed in many soil properties is unlikely. The elemental inventories from the present study showed no clear pattern between profiles, Profile 2 showing the highest N inventory but the lowest P inventory and Profile 4 the lowest N inventory but the highest P inventory; the profiles were 50 m apart. Furthermore, the differences between profiles were smaller than the differences in accumulation rates between the two locations. As shown in Table 1, the elemental inventories on Putauhinu (an island close to Taukihepa) were similar to those on Taukihepa.

In conclusion, the present study supported earlier results showing low rates of retention of seabird nutrients in colony soils. The higher elemental accumulation rates observed on Adams Island compared with literature results from Taukihepa can be explained by a combination of a colder climate and poorer litter quality on Adams Island. I recommend further determinations of nutrient retention rates in seabird colony soils, as opportunities arise.

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